Aerobot Autonomous Navigation and Mapping for Planetary Exploration

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Airship as a platfrom for planetary exploration

Airship is a good platform to perform a wide variety of measurements:

1. Dynamics properties
   - Good controllability
   - Position along given trajectory and **altitude**
   - **Speed** (low velocity)
   - Station keeping capabilities
   - Very stable attitude, no vibrations
2. Long duration mission capabilities
3. Long distances travel capabilities
4. No obstacle avoidance problem wrt rovers
5. Low power consumption

Measurements

RESOLUTION

DISTRIBUTION

Mission Profile : Orbiter + Airship

- Orbiter – airship direct link: command/data handling and geo-referencencing
- Orbital period:

  5.2 hours

- Communication cycle:

  14 orbits 35 to 75 minutes link

  5 hours full autonomous navigation
  with bounded uncertainty

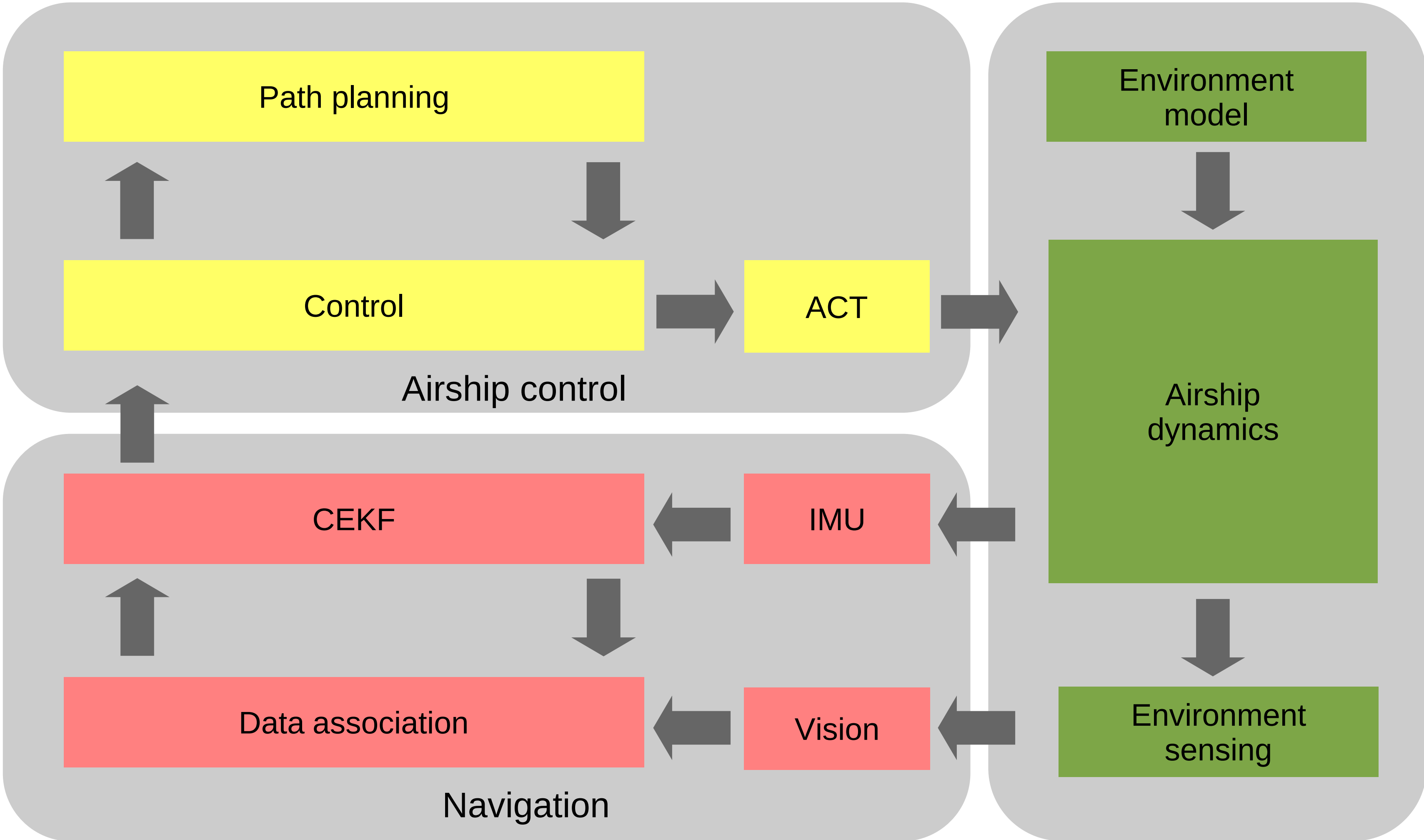
  4 to 6 days no link

  High altitude navigation and/or station keeping

1. Airship has an assigned path
2. Autonomous navigation
   1. Journey
   2. Mapping
   3. Dedicated survey to specific areas: hovering, circling or ground interactions

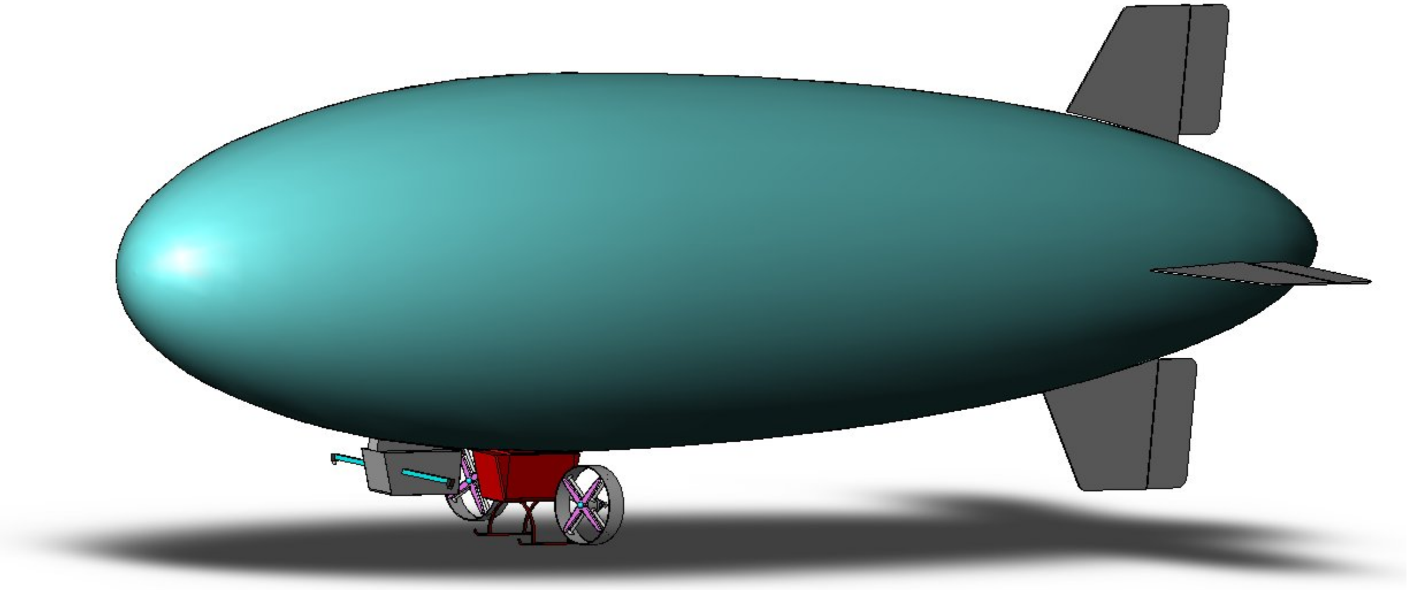
Credits Titan Explorer mission: NASA Vision Mission Study per NRA-03-OSS-01 – year 2005

Airship simulator



Simulation process

1. Identification of test cases
2. Identification of favourable site for testing (Sikun Labyrinthus selected)
3. Generation of the desired trajectory (via way points)
4. Simulation of the complete aerodynamics of the airship for each test case
5. Trajectory and dynamic reconstruction via SLAM technique
6. Mapping of the overflown terrain
7. Error identification



Titan environment

Titan parameters dependent from altitude:

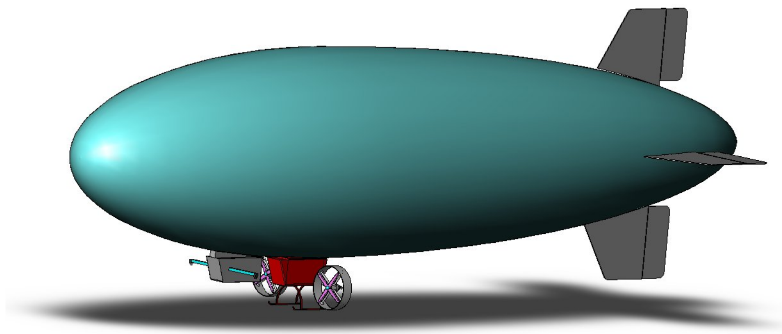
- Gravity
- Dynamic viscosity
- Density

- Wind dependent on altitude or time; random direction and strength

- Sikun Labyrinthus area (78S, 29W)

Credits: Hypothetical relative elevation model by Mike Malaska

Airship characteristics:



- 17.5 m length, max diameter 3.5 m
- 25 kg payload, total weight 313 kg
- Control actuators:
    - Main thrusters with rotation capabilities (up to 30 °)
    - Pitch and yaw rudders on tail
- Mono and stereo vision capabilities

Credits Titan Explorer mission: NASA Vision Mission Study per NRA-03-OSS-01 – year 2005

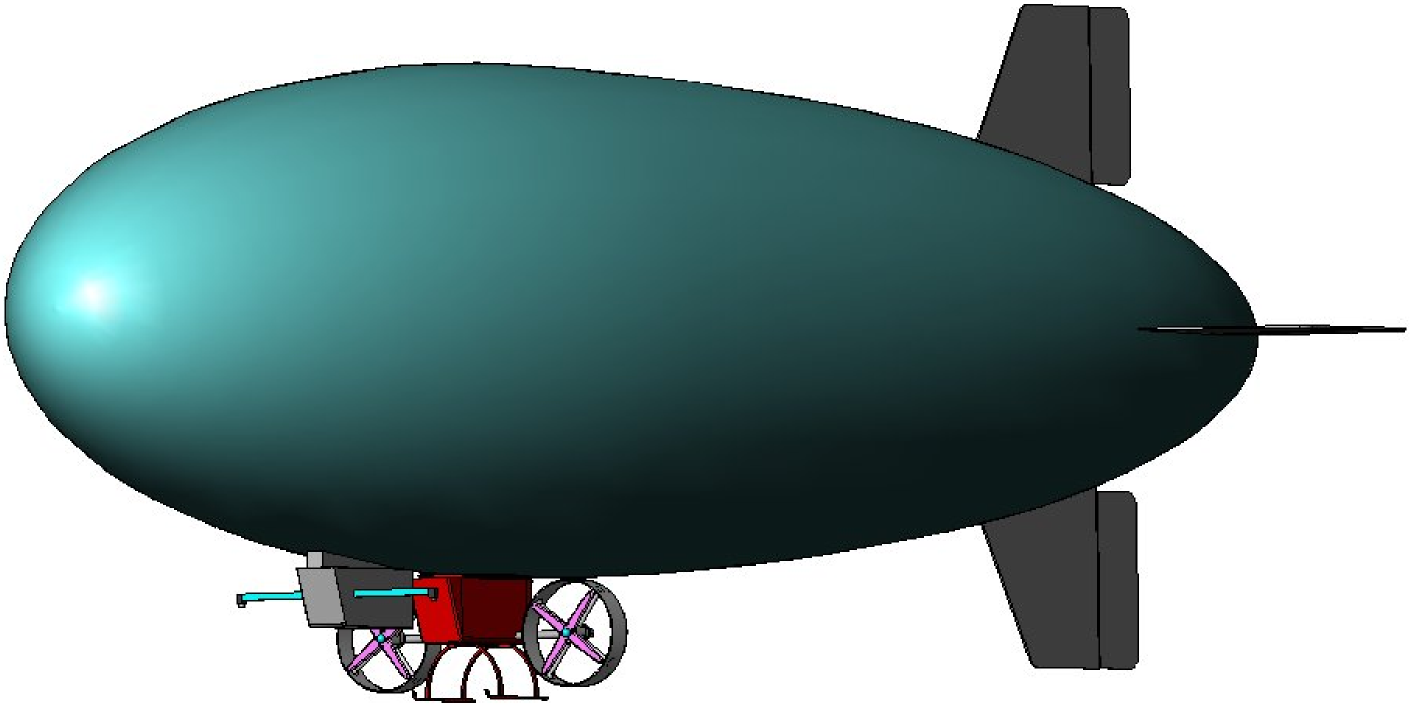
Mission Profile : needed measurements

Measurements and informations required for autonomous operations:

- Airship attitude
- Airship velocity and position wrt last reference position (from orbiter)

Needed to

- Georeferencing measurements
- Path planning
- Trajectory control



Simultaneous Localisation and Mapping (SLAM):

SLAM algorithms goal is to :

1. Incrementally Build a map of an unknown environment

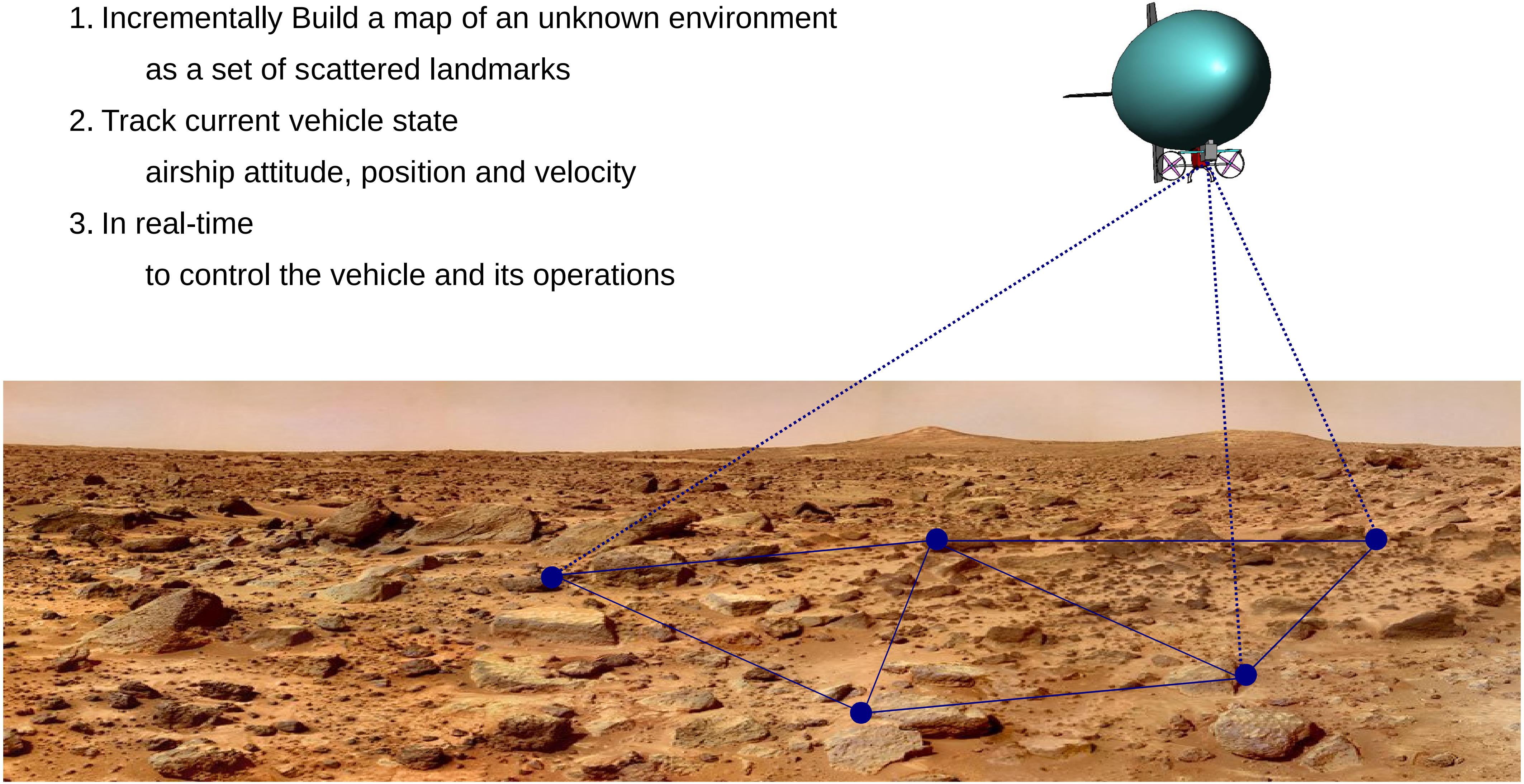
    as a set of scattered landmarks

2. Track current vehicle state

    airship attitude, position and velocity

3. In real-time

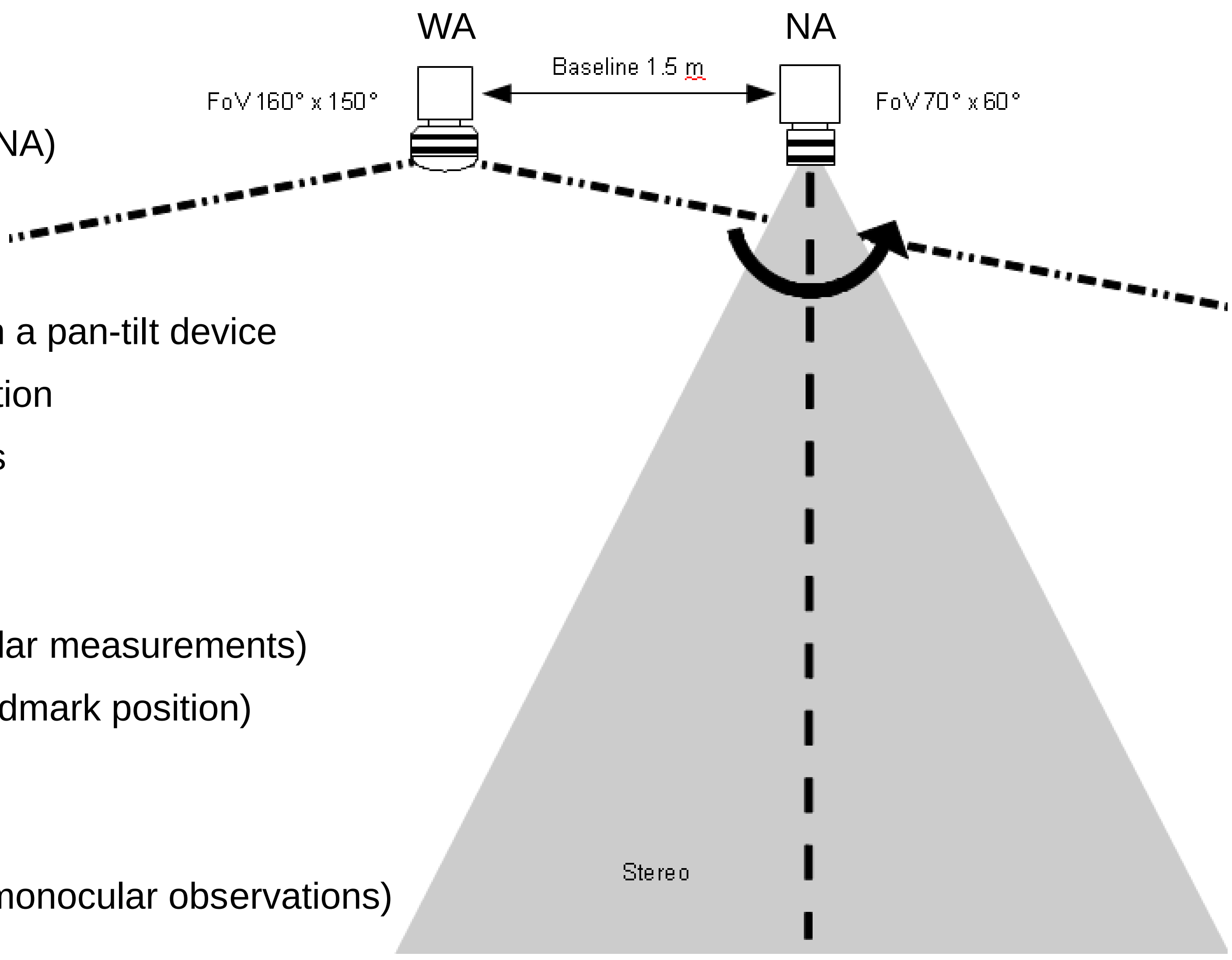
    to control the vehicle and its operations



Vision sub-system:

Two cameras :

- Fisheye wide angle (WA)
- High resolution narrow angle (NA)

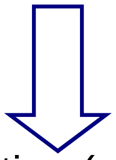


The NA camera can be mounted on a pan-tilt device

- Alignment with direction of motion
- Tracking of interesting features

Algorithm designed to process

- Monocular observations (angular measurements)
- Stereo observation (full 3D landmark position)

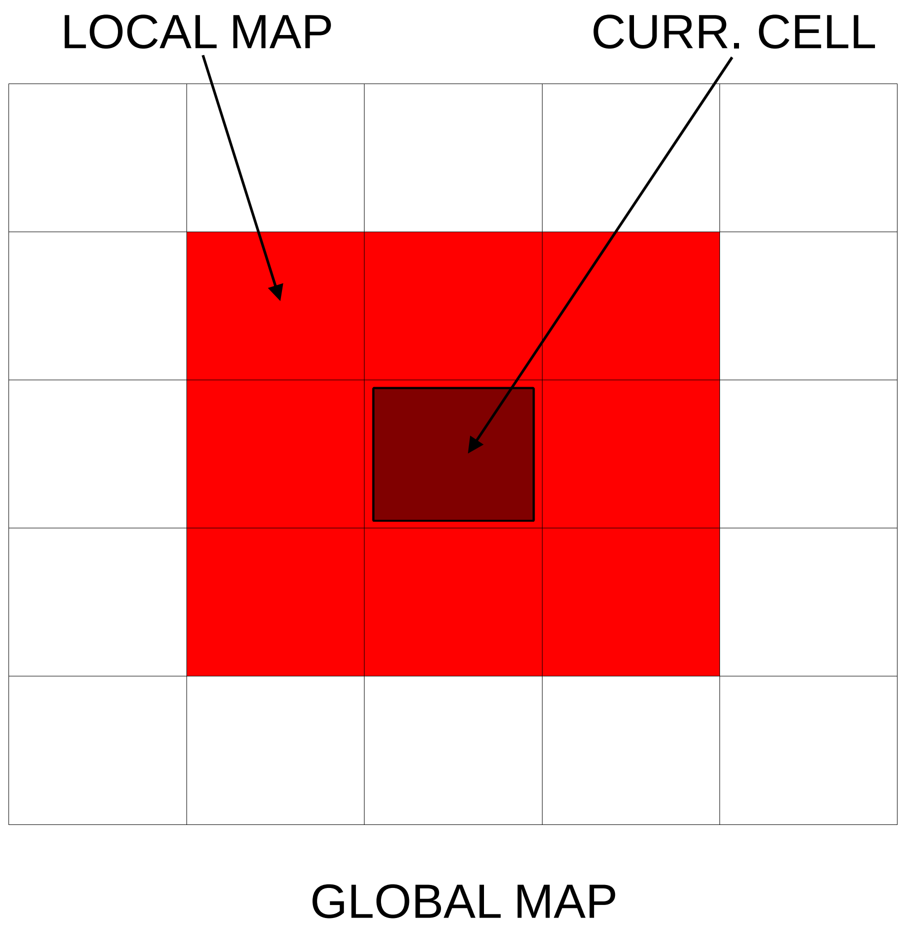


- High altitude navigation (only monocular observations)
- Failure of one of the cameras

Compressed Extended Kalman Filter:

Extended Kalman Filter algorithm :

- Integrates IMU measurements (50 Hz)
- When available, process measurement of visible landmarks (4 Hz)



Improvements are needed to

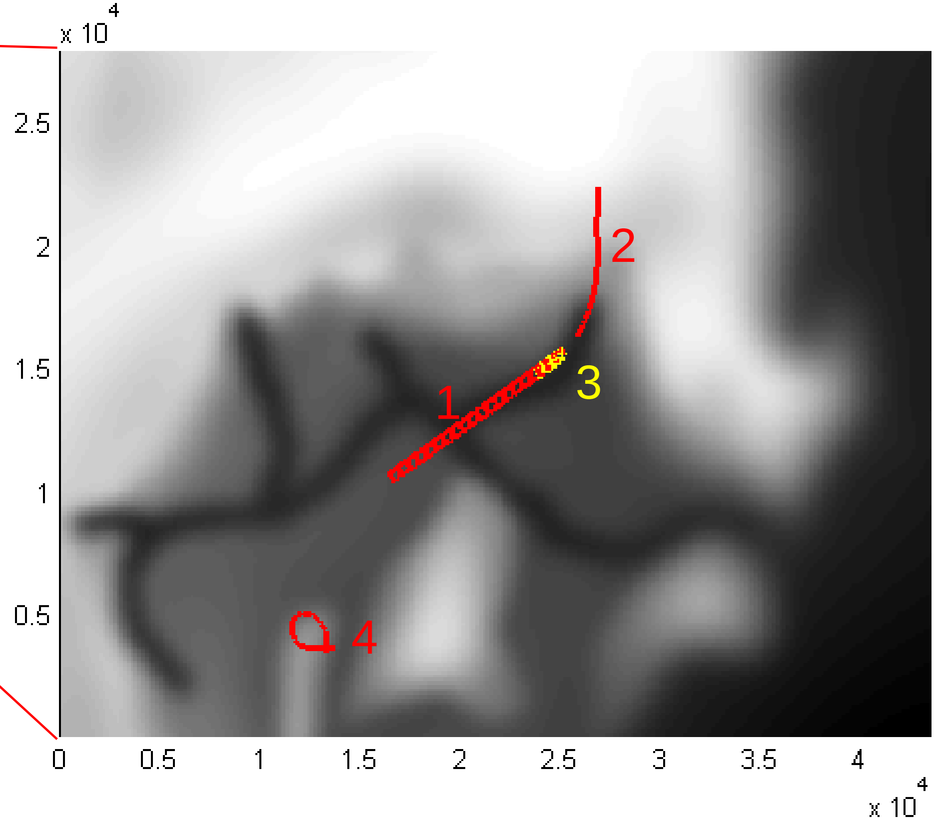
- Reduce computational load
- Manage large maps

“Compressed” implementation :

- Process only landmarks closer to the vehicle depending on the vision S/S range capabilities (local map)
- Update the whole map only when vehicle change cell (global map)

CEKF video: An example

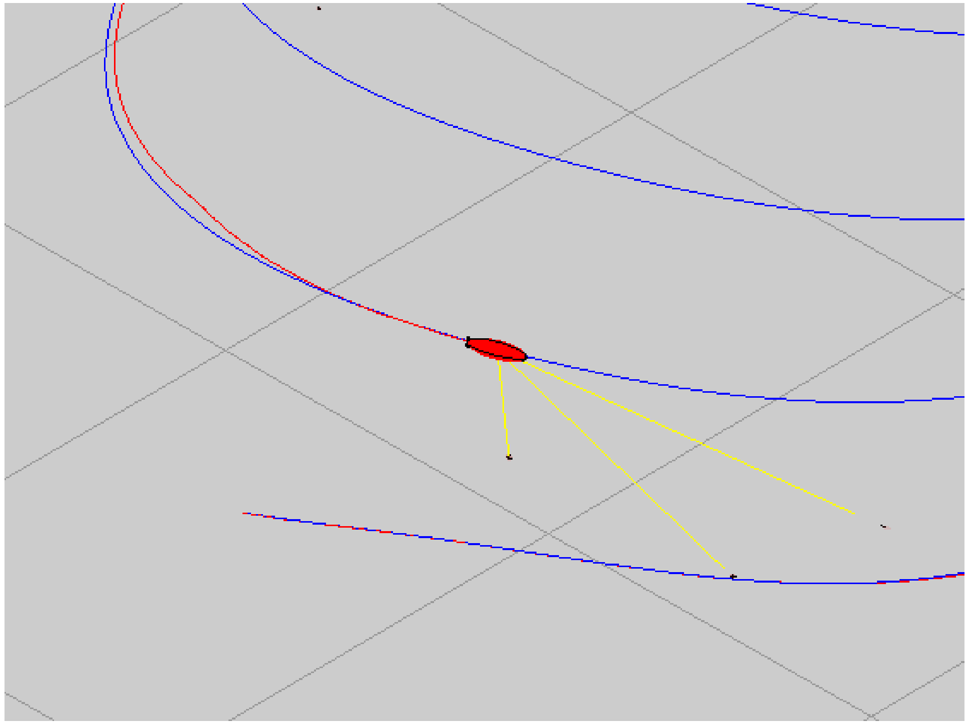
Test cases



1. Long transfer
2. Straight trajectory - canyon entering
3. High resolution mapping of scientific interesting area
4. Hill analysis

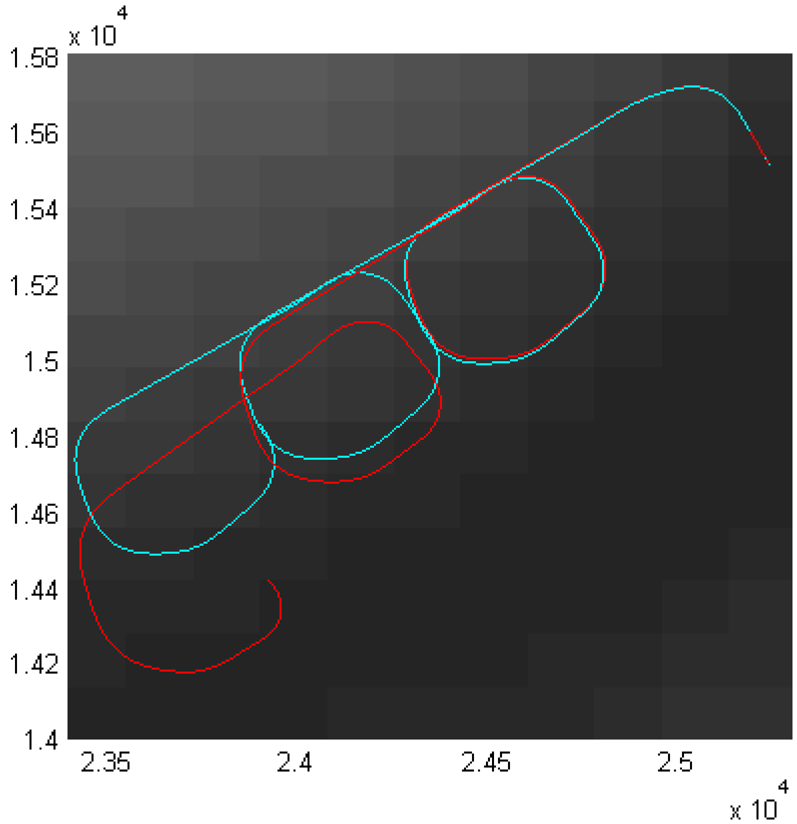
Test cases: trajectories parameters

Airship velocity	= 5 m/s	(controlled)
Travelled distance	= 6300 ÷ 80000 m	
Trajectory time	= 0.3 ÷ 5.2 hrs	
Wind values	= 0 ÷ 1.0 m/s	
Observed area	= 0.68 ÷ 15.6 km^2	

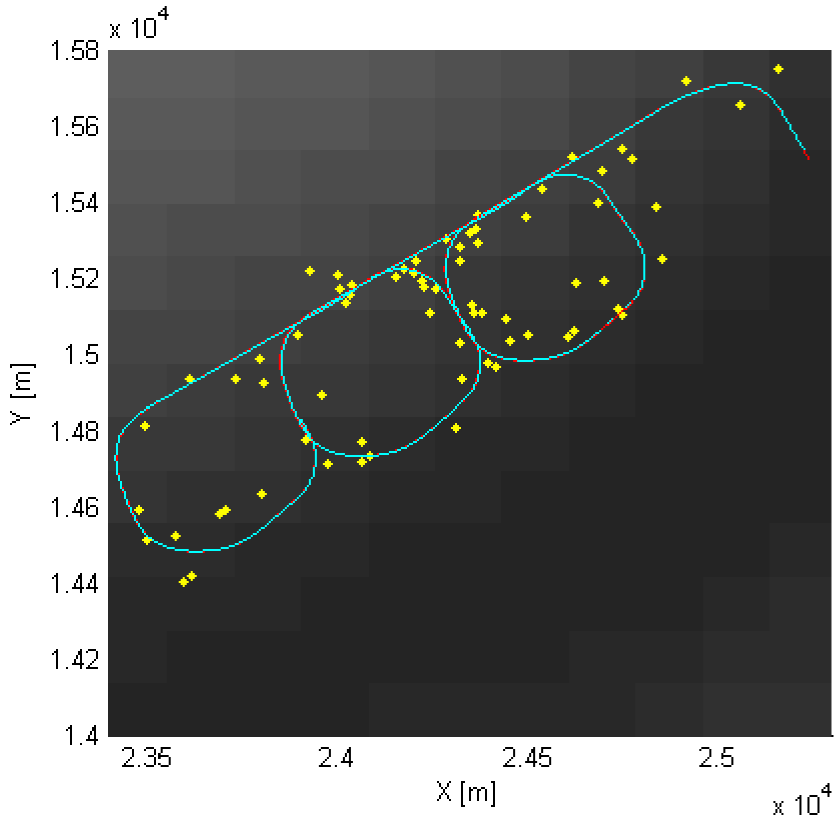


Trajectory reconstruction: used measurements

Inertial measurements

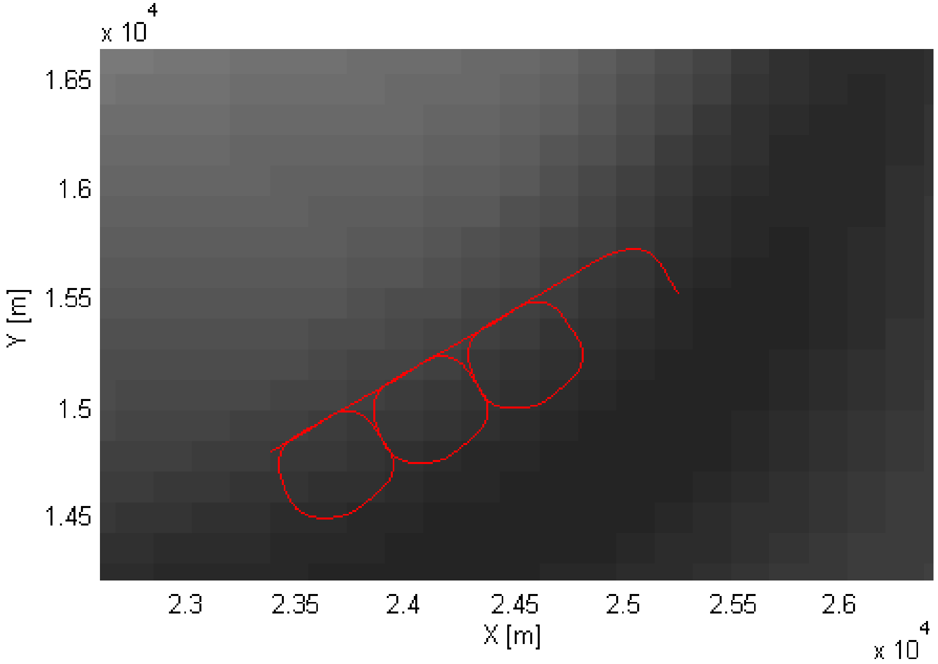


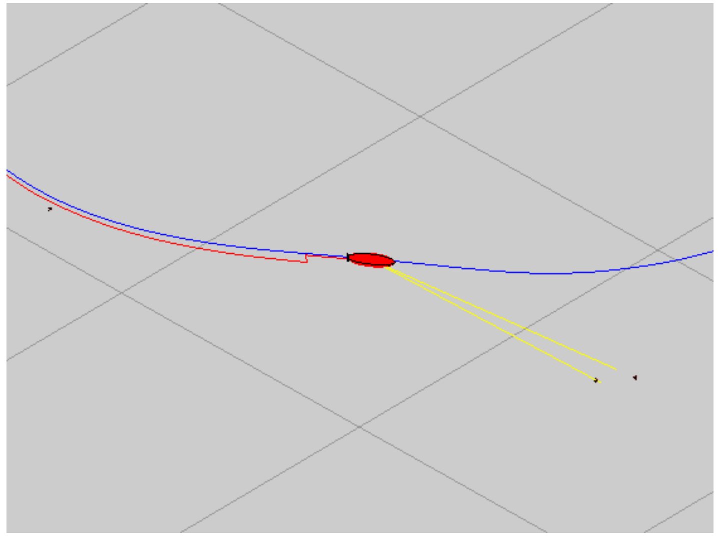
Inertial measurements
+
vision system

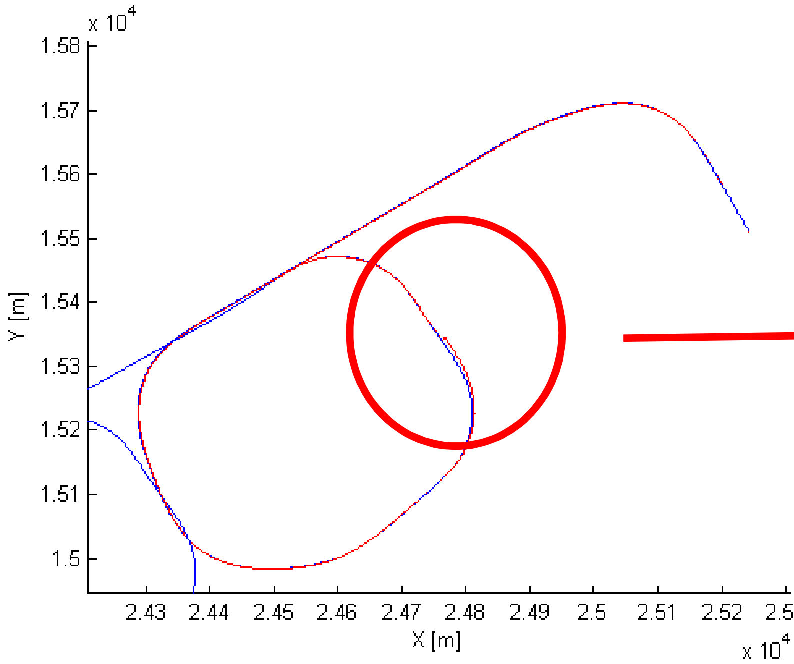


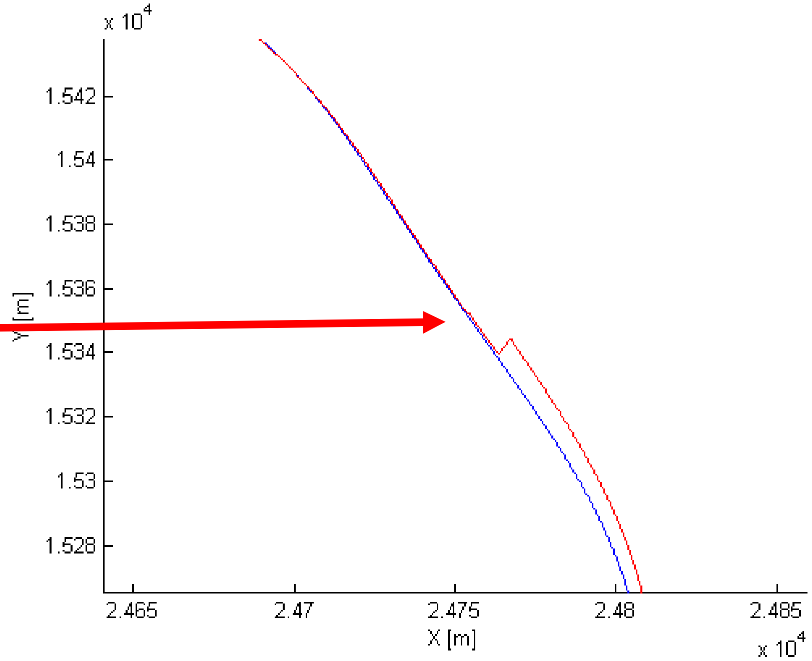
Prediction rate = 50 Hz
Filtering rate = 4 Hz

Trajectory reconstruction: loop closure

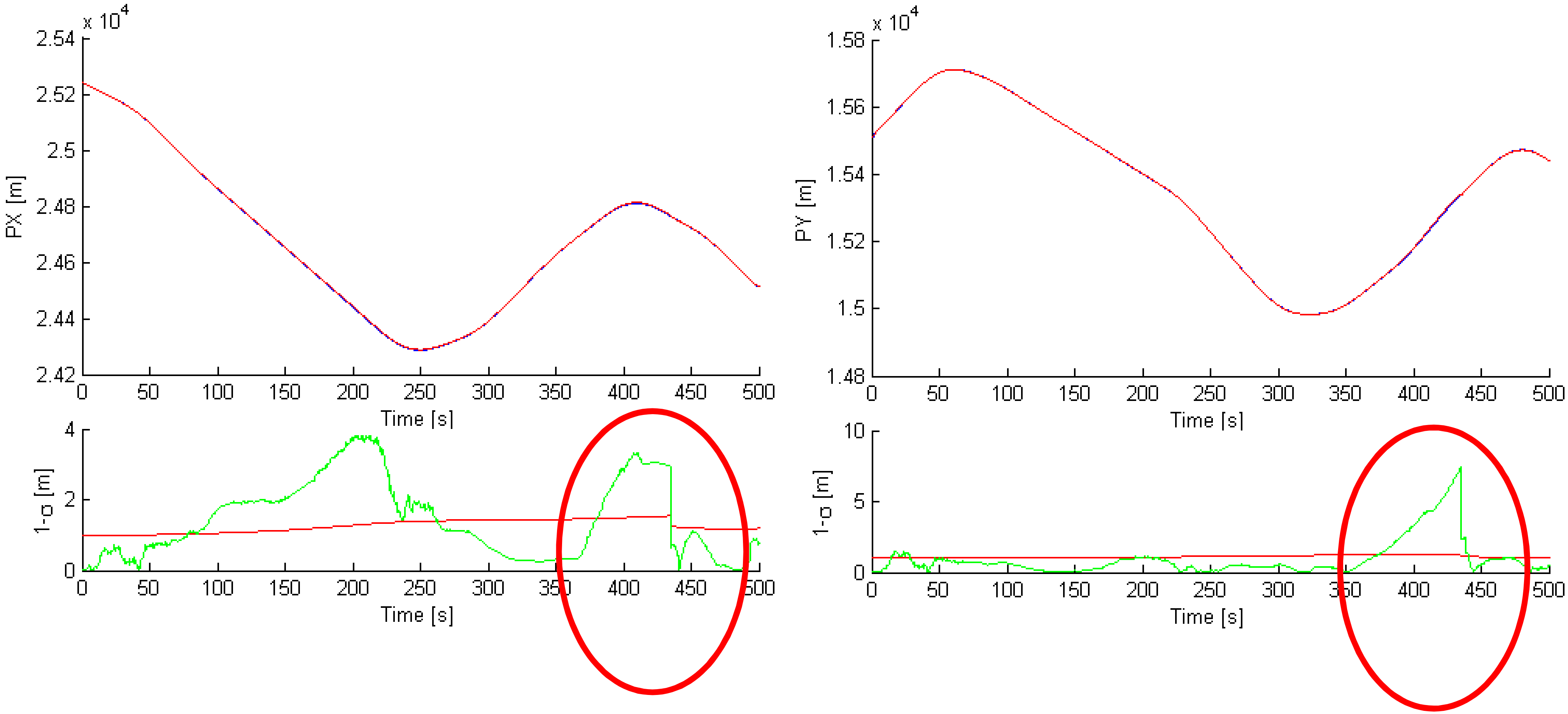






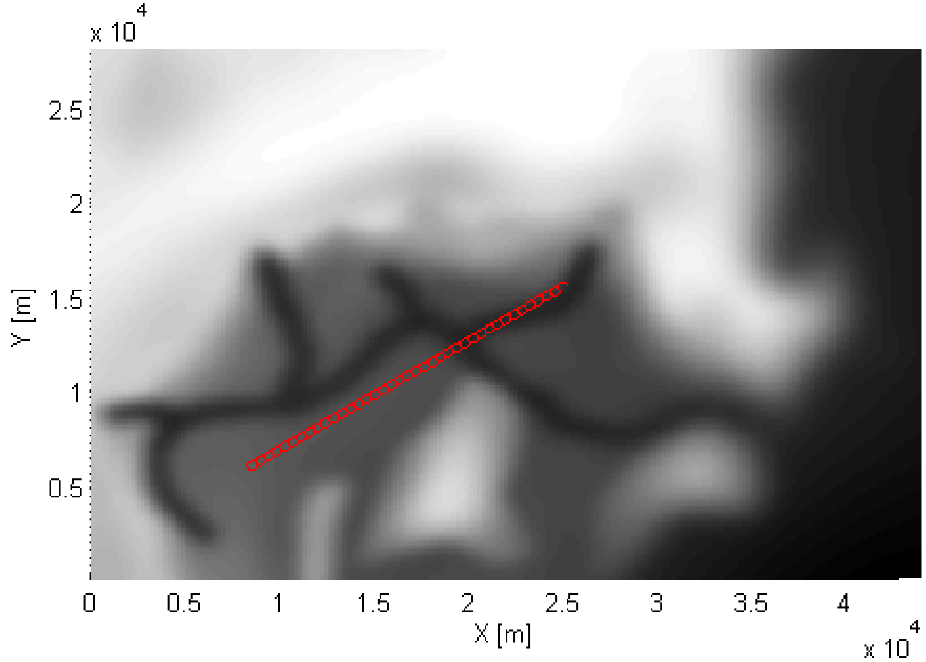


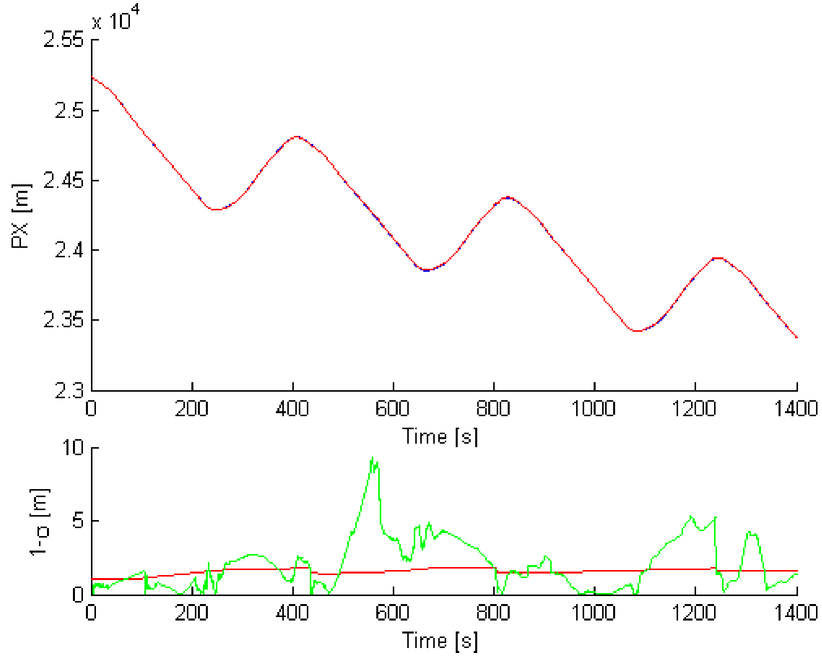
Trajectory reconstruction: loop closure

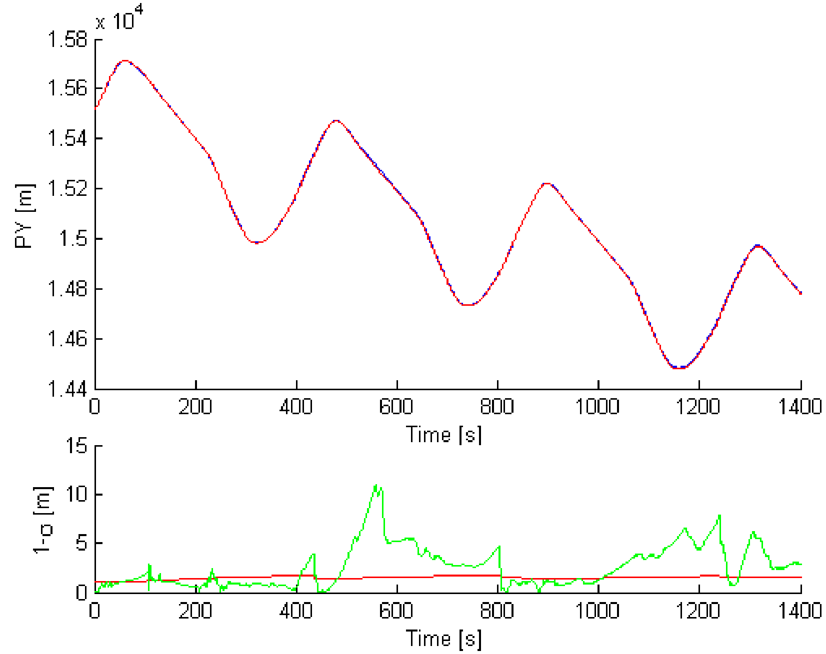


1. Long transfer

		3 cells	full trajectory	
Travelled distance	=	2000	26000	m
Length	=	6800	88400	m
Total time	=	0.4	5.2	hrs
Errors				
X position error	=	1.4	18.2	m
Y position error	=	3.0	39	m

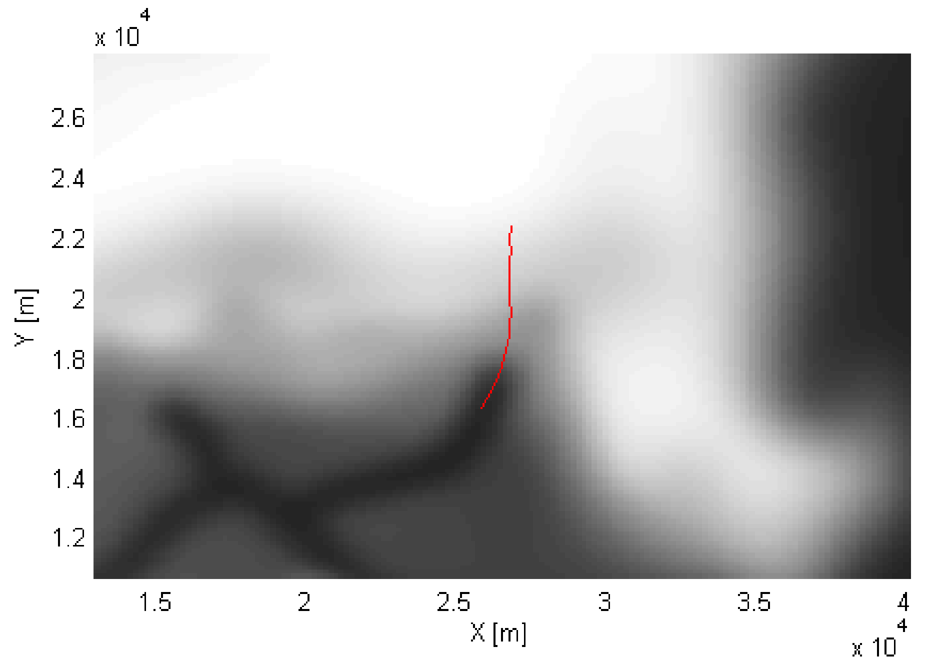


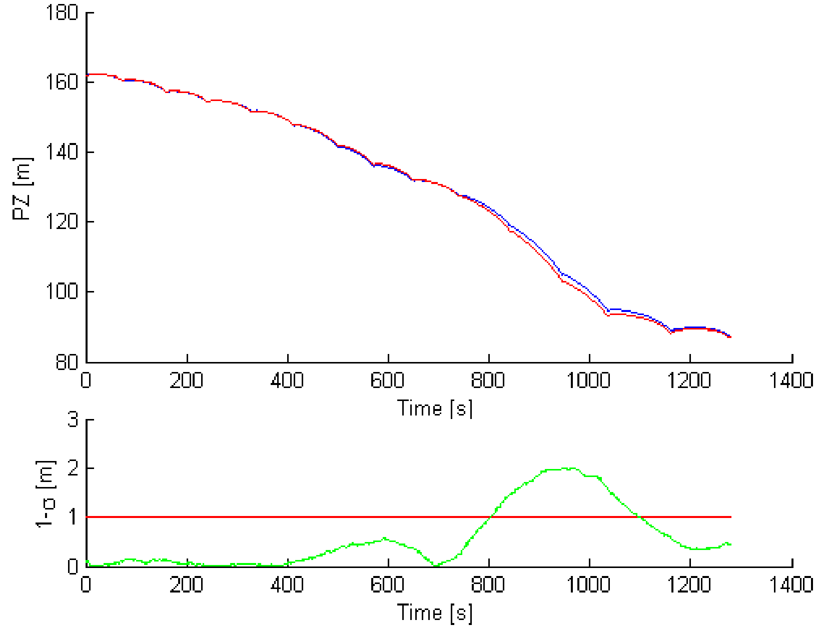


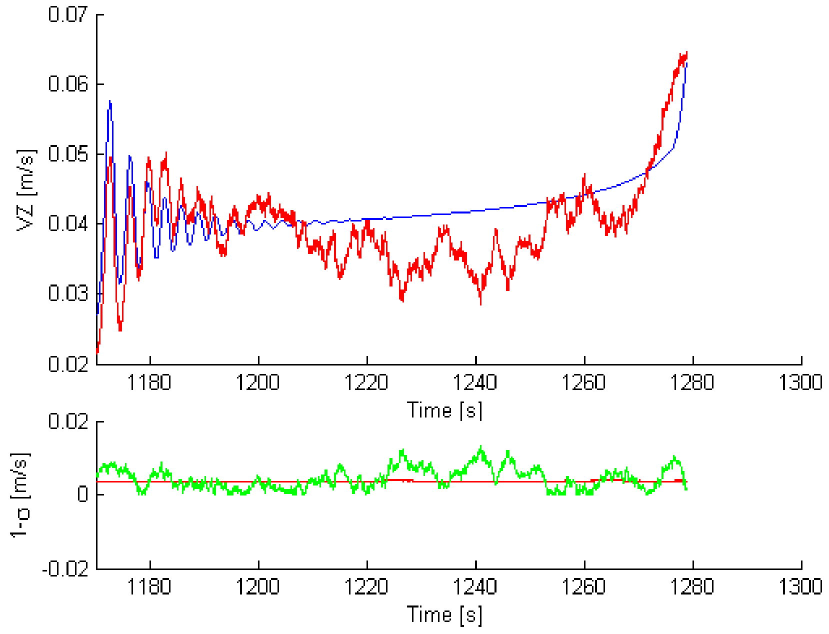


2. Straight trajectory - canyon entering

Travelled distance	= 6300	m
Altitude variation	= 74	m
Total time	= 0.35	hrs
Errors		
X position error	= 10	m
Y position error	= 6	m
Z position error	= 0.4	m







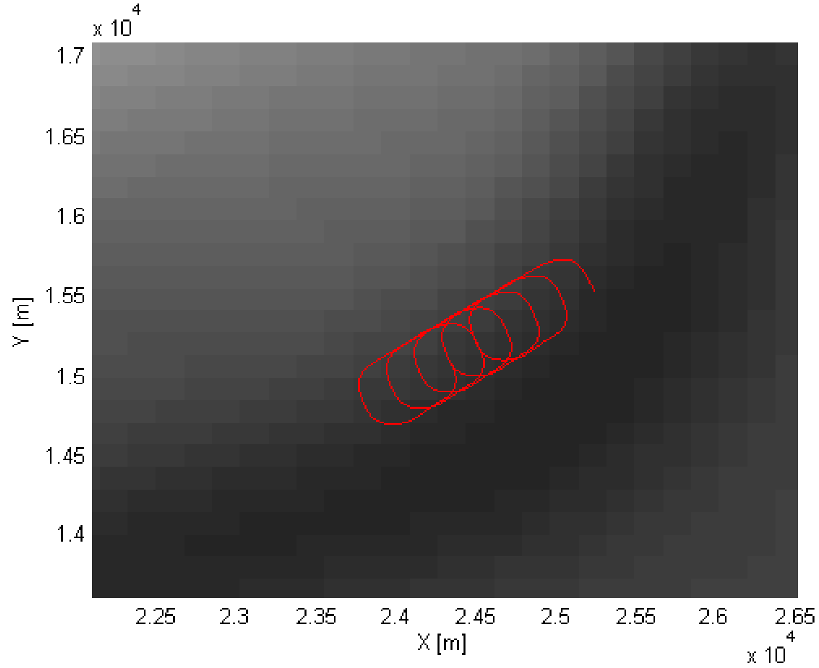
3. High resolution mapping of scientific area

Travelled area = 1600 x 420 m

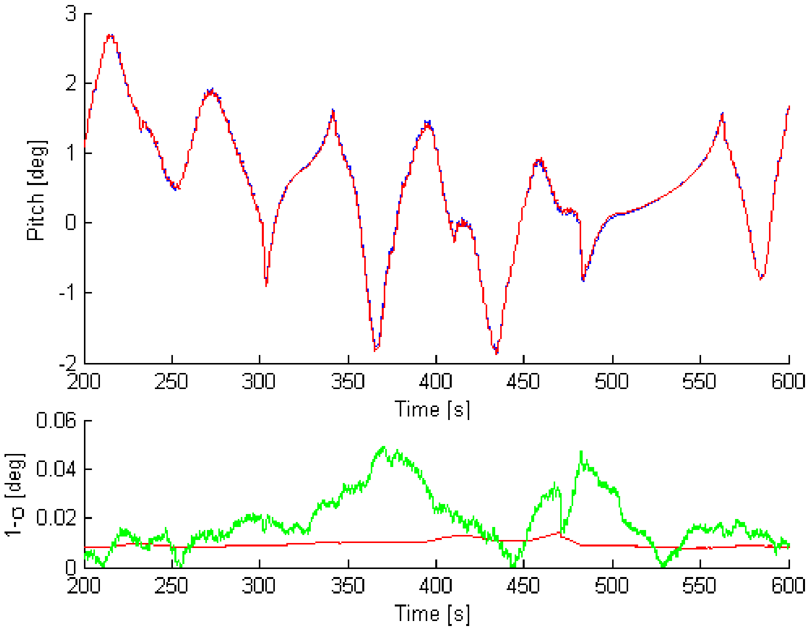
Observed area = 0.68 km^2

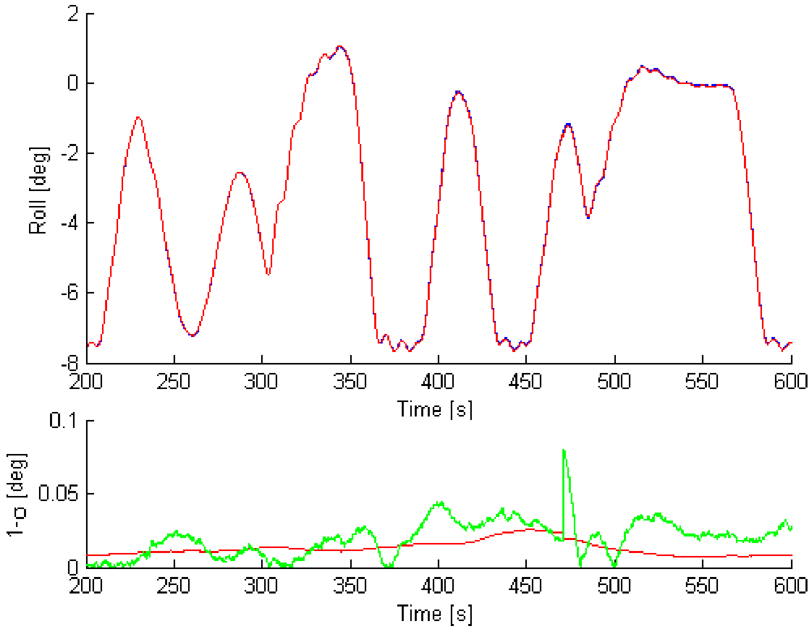
Total length = 9810 m

Total time = 0.55 hrs



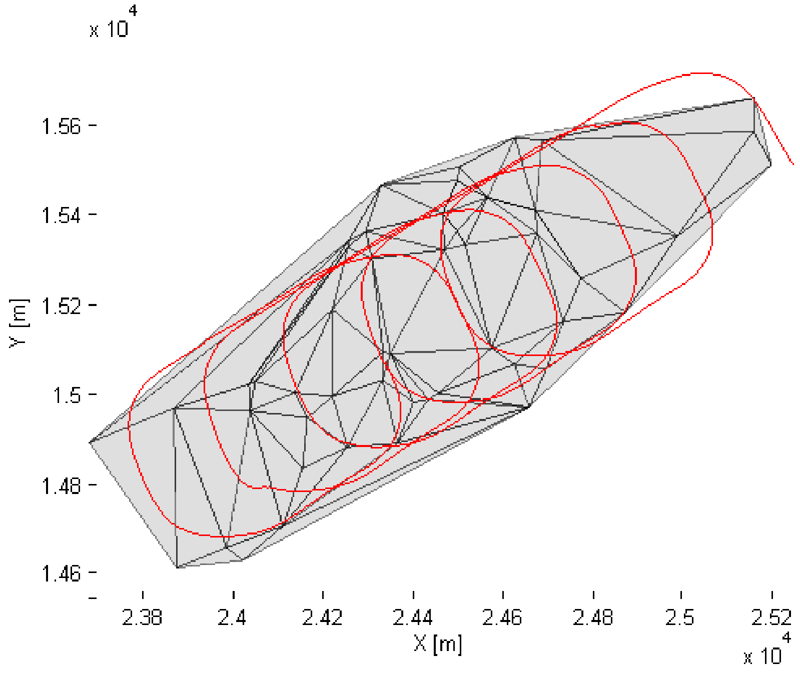
Attitude during 1 loop



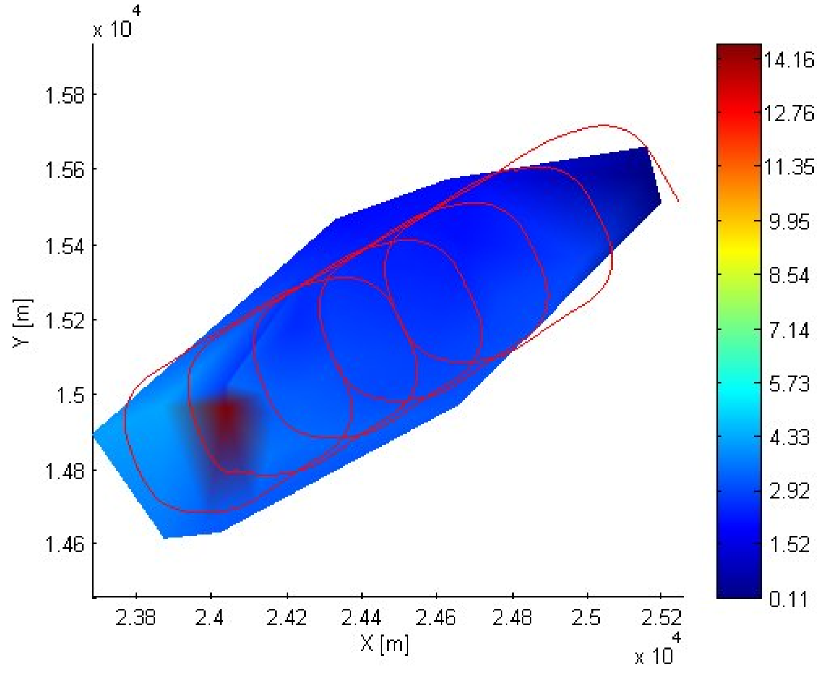


3. High resolution mapping of scientific area

Reconstructed DTM



Reconstructed DTM errors



4. Hill analysis

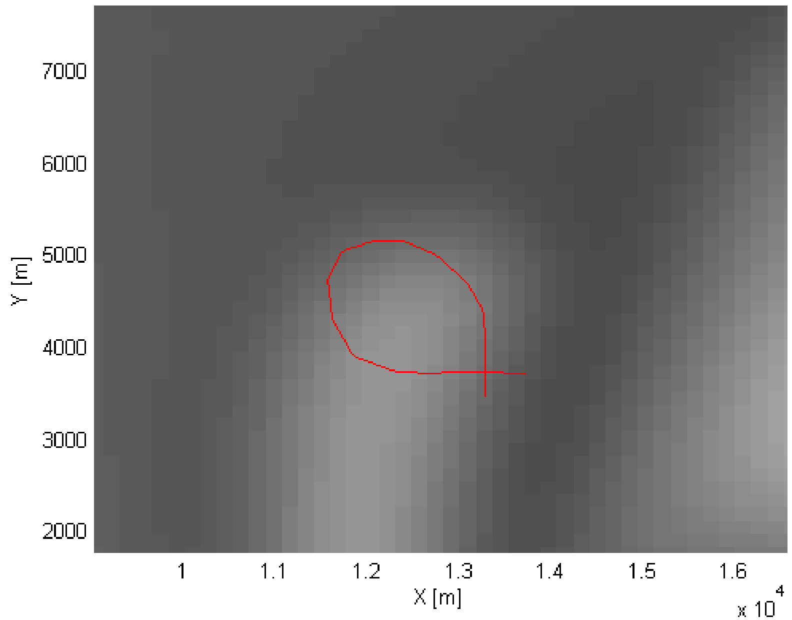
Travelled distance = 5900 m

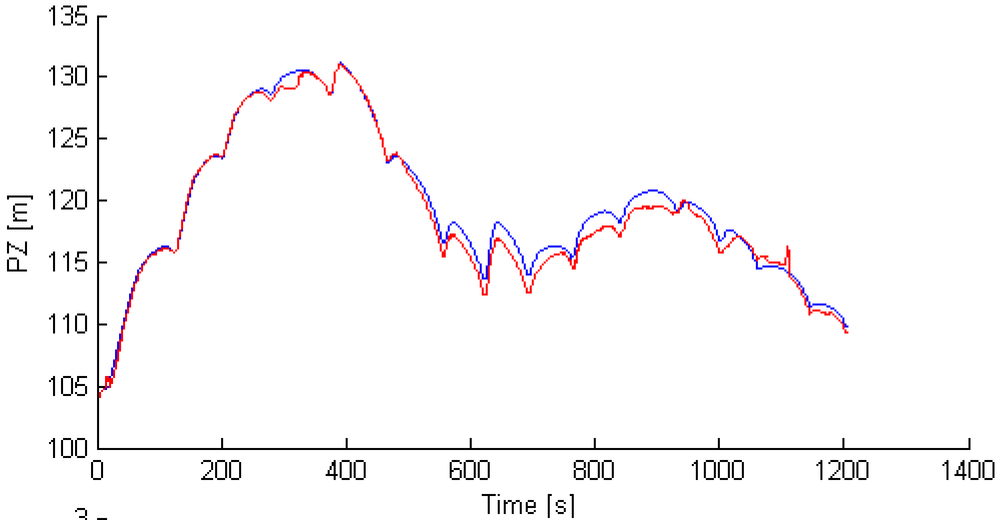
Altitude variation = 27 m

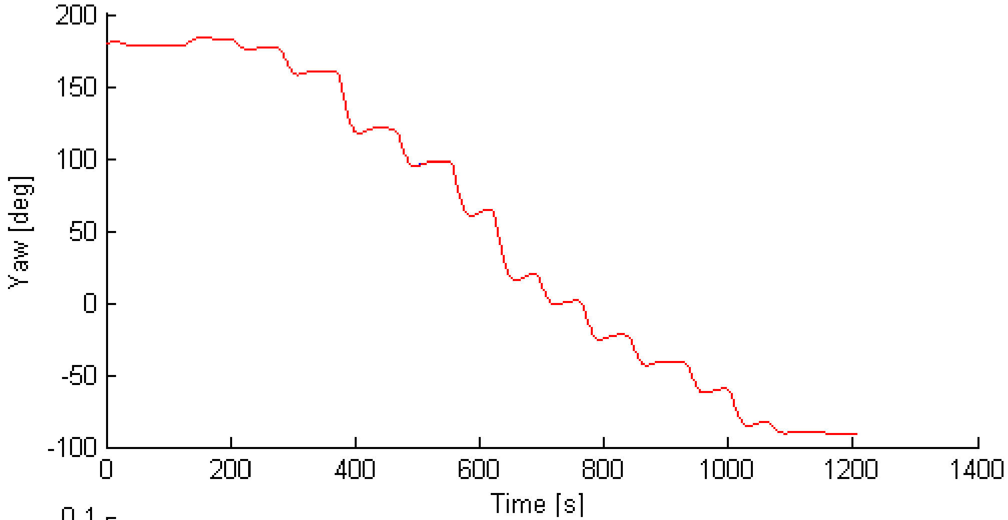
Total time = 0.35 hrs

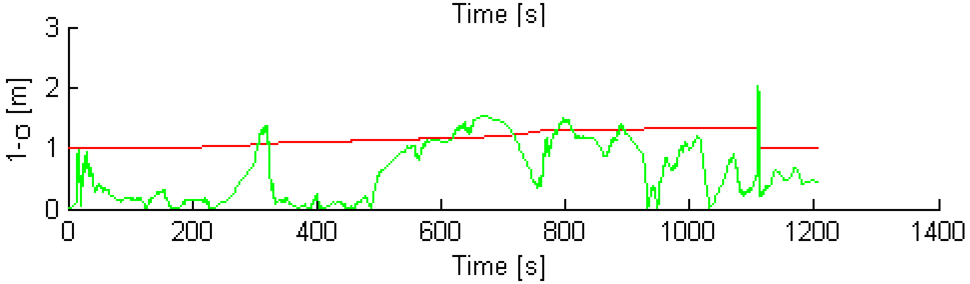
Errors

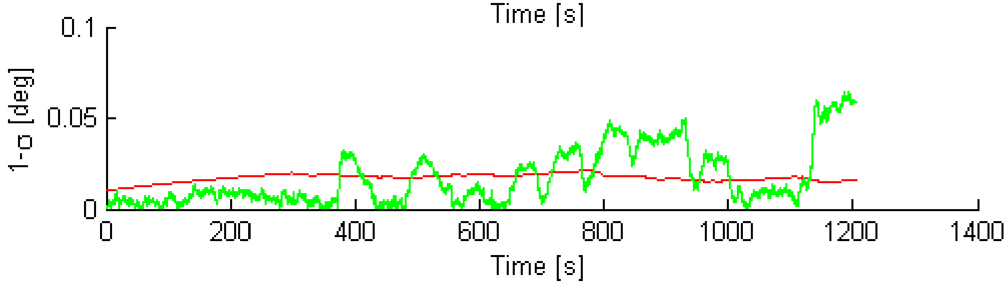
Z position error = 0.3 m











Conclusions:

A consistent simulator of an airship has been developed considering:

- Aerodynamics
- Environmental conditions
- Control actuators dynamics
- Navigation system

Navigation system, sensor parameters and data processing algorithms have been identified, and tested.

Overall system performances have been evaluated through simulation to assess the effectiveness of this vehicle for mapping applications thanks to its:

- Controllability
- Attitude stability

Different type of trajectories have been tested:

- Long transfer
- High resolution scientific area
- Canyon entering

At now a prototype is under development, first test campaign is planned for end 2010!

Annex - system sensors spec. :

IMU

Nav. grade   Gyro drift 0.005 °/h   Acc drift < 50e-6 g

Camera

Pixel no   2540 x 2050   Pixel size   3.45e-6 m

NA camera optics

Focal length   6 mm   FoV   70 ° x 60 °

WA camera optics

Focal length   3 mm   FoV (used)   160 ° x 150 °

Stereo NA - WA

Baseline   1.5 m

Depth [m]	Footprint [m]	Resolution [m/px]	Z unc. [m]	X,Y unc. [m]
25	33.7 x 29.5	0.014	0.34	0.24
95	132.3 x 112.0	0.055 - 0.200	4.90 - 13.00	3.45 – 6.19

Monocular NA

Depth [m]	Footprint [m]	Resolution [m/px]
100	140.9 x 117.9	0.058
500	704.4 x 589.4	0.288

Monocular WA

Depth [m]   Footprint [m]   Resolution (image center) [m/px]

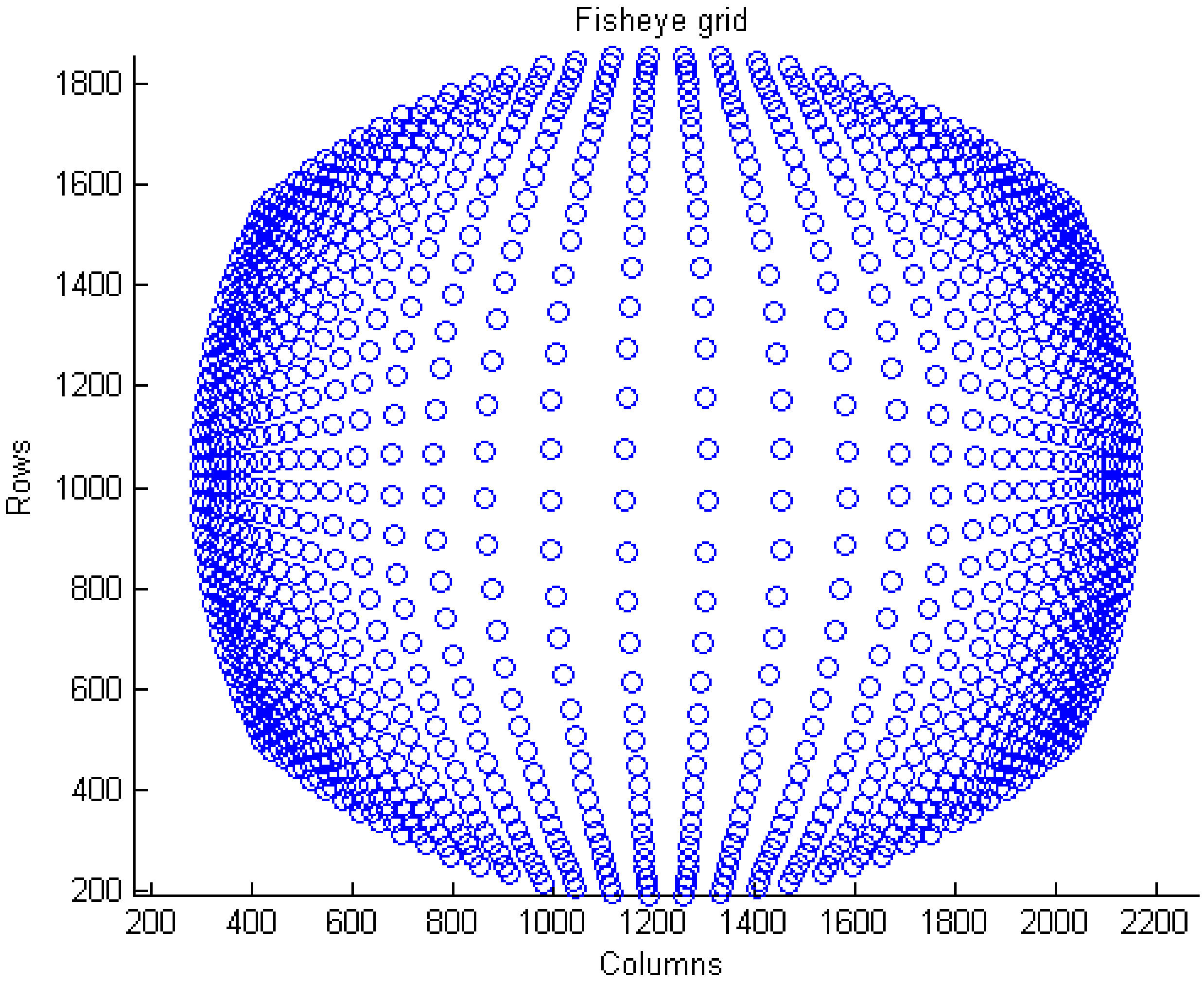
10   113.4 x 74.6 0.019

50   567.0 x 373.2   0.100

100   1134.3 x 746.10.200   500

5671.3 x 3732.1   1.005

Annex – fisheye camera grid :



Annex - CEKF measurement processing :